REFERENCE·TEMPLATE GENERATION FOR
AUTOMATIC TARGET RECOGNITION (ATR) SYSTEMS

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1. Abstract

This paper discusses Northrop Grumman's solution to the problems associated with existing methods for the generation of reference templates for Automatic Target Recognition (ATR) Systems. Reference templates are used by ATRs of sensor systems to provide sufficient definition of the target in order to autonomously detect, identify, and track the target. Existing methodologies typically rely on the expertise of the user to predict the characteristics of the target in the waveband of the sensor and to manually create a reference template. Such reference templates are limited by the conditions for which they were planned and by the knowledge base of the user. In addition, they do not provide any prediction of the success associated with the reference template. Northrop Grumman has developed and validated a method of automatic reference template generation for imaging infrared (IIR) sensors that eliminates these limitations and inadequacies. By utilizing a prediction of the sensed target image and the sensor's ATR, the method generates a reference template that is insensitive to changes in conditions that affect the sensed target image. The method also provides a prediction of the success of the reference template by means of a probability of acquisition (P_{ACQ}). Although developed for IIR sensors, the methodology is applicable to other advanced sensor systems.

2. Overview

The next generation of terminal sensors for precision guided standoff weapons will incorporate all-weather imaging capability with Automatic Target Recognition (ATR) techniques to detect and identify targets amid varying degrees of ground clutter. Examples of sensor systems in this category are imaging infrared (IIR), laser-radar (Ladar), and synthetic aperture radar (SAR). Common to each of these sensor systems is the requirement for target planning, i.e., providing sufficient definition of the target such that the sensor ATR process can successfully detect, identify, and track the target.

Two primary processes comprise target planning:

- Reference template generation

- Performance prediction: the evaluation of the reference template against the conditions under which it will be used

A reference template is utilized in automatic target recognition as the basis for comparison with the sensed image to identify the point of correlation in the sensed image. This point of correlation is then used to generate guidance commands for the vehicle, as appropriate. The reference template for an IIR ATR may represent anything in the image, either discrete or abstract, as the correlation process typically is performed in only two-dimensions. However, other wavelength or multi-band (dual-mode) sensors typically correlate in all three dimensions.

In addition, since the scene properties detected are a function of the wavelengths of the sensor, the reference template is highly dependent upon the operating frequency band of the sensor. For example, an IIR sensor is detecting temperature differences while a millimeter waveband (MMW) sensor may be detecting reflected MMW

energy. In nearly all cases, the reference template will be different for the two wavebands.

For any given waveband, the ATR algorithms themselves can influence the generation of reference templates. Some ATRs discern particular patterns, shapes, relative image contrast, or other relationships more readily due to the unique nature of the ATR image processing algorithms. Often these built-in biases are intentional and intended to improve recognition performance for a particular set of circumstances.

In the case of IIR ATRs, the reference template most commonly represents lines of temperature difference or contrast, although other approaches have been used. The advantages to the use of contrast edges include reducing the number of pixels processed compared to other methods (improving throughput), a reduction in the required geometric knowledge of the target area, and the simplification of reference template components.

In the current military and political climate, military commanders require a quantifiable probability of mission success prior to weapon employment. Future systems will require such information not only prior to the mission, but during the mission as they are updated or planned in real-time. A significant problem in fielding an advanced ATR sensor is predicting both imaging and ATR performance of the sensor system prior to mission execution or in real-time. Sensor system performance prediction, *a priori*, has been a formidable task primarily due to the vast number of variables, large extent of variable range, and high degree of uncertainty associated with each variable.

For example, performance of an IIR sensor system is typically dependent upon variables in mission scenario, geo-location, season, time, weather, scene content, et cetera. Weather alone consists of temperature, humidity, cloud cover, cloud type, precipitation, wind direction and wind speed, each represented as a function of time. The individual variables not only have a

wide range, but also a high degree of uncertainty within that range.

The criteria against which to measure target planning approaches is dependent upon the application, the planning environment and other external constraints such as available time to plan, skill level of the operator, intelligence data required, robustness (correlation in all conditions), and acceptable level of risk (of miss), among others. In addition, the concepts of faster, easier, and cheaper are clearly benefits when all other factors are considered equal. The ideal target planning approach should meet the following requirements:

- Minimal reference template generation time

- Minimal intelligence data

- Generate reference template that provides all coverage (weather, heading and time on target)

- Provide the user with confidence in the correlation performance of the reference template

- Little or no training of users

- Low development cost

These issues are addressed in the following discussions of reference template generation methodologies.

3. Existing Reference Template Generation Methodologies

The task of creating or defining a reference template for automatic target recognition utilizing IIR sensors has been approached using several methodologies. Five existing approaches are discussed in this section. A summary of features for each of these approaches and a Northrop Grumman approach that is presented in Section 4 is shown in Table 1.

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Table 1 Feature Summary

System	Reference Template Generation Method	Decision Aids	Sensed Image Simulation	Sensor ATR Simulation	Performance Predication
Expert Manual Planner	Manual	None	No	No	No
Expert Aided Planner	Manual	External	External	No	No
Expert System	Manual	Yes	Yes	No	No
Discrete Model System	Manual	Yes	Yes	Yes	No
Random Model System	Automated	No	No	No	No
Northrop Grumman Automated Reference Template Generation	Automated	Yes	Yes	Yes	Yes

3.1 Expert Manual Planner

The expert manual planner relies heavily on past experience, expertise, and judgment. Features to be included in a reference template are based on the planner's own expertise in IR phenomenology, and understanding of the ATR employed. Little or no reference materials, manual or automated tools, or other decision aids are utilized. Reference template construction requires a complex analysis of intelligence data. Photo-interpretation is needed to estimate material types and mentally visualize the target along the flight path. Such a system has low development costs, but the operational costs are high due to highly skilled personnel, long reference template generation times and extensive intelligence data required.

As an example, let Figure 1 represent an IR rendering of a scene that an expert planner has tested against before. The image represents a specific location and time (19:00), under clear weather conditions. Based on the thermal signature, the expert chooses to include the roof features in the reference template. If the reference template is flown against the same target at the same time of year, the same time of day, at the same heading and profile, and under exactly the same weather conditions as before, the probability of successful acquisition would be quite high. However, the probability of all of the above conditions being the same is very small. Figure 2 shows the scene with all conditions the same, except that the time of day is 03:00. Figure 3 shows all conditions the same with the exception of an overcast sky. It is clear that the reference template would not be adequate under the conditions of Figure 2 and Figure 3, as well as a multitude of other possible variations. If the planner chooses to fly the reference template outside the realm of past experience, he must arrive at a "best guess" of the thermal signature under the new conditions. Any variations must be very carefully considered, and reference templates become very specialized, i.e. they are not robust. Not only does this make the process extremely time consuming, it also does not give the planner much confidence in reference template correlation performance.
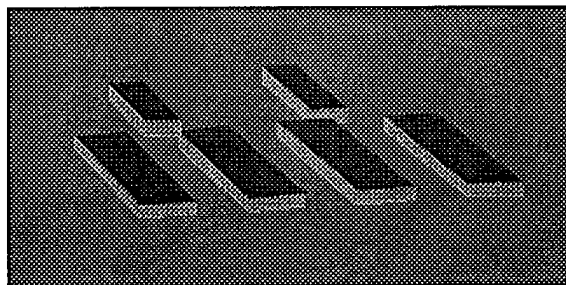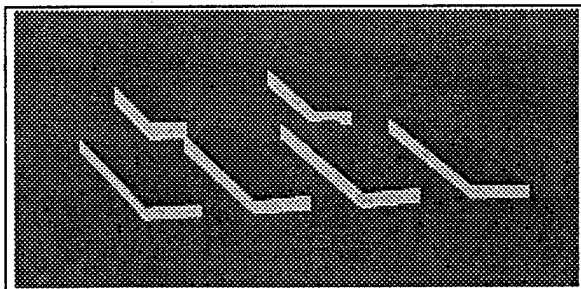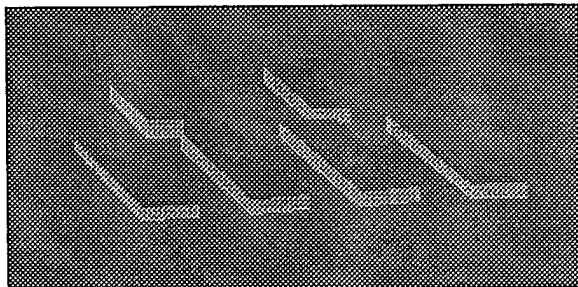

Figure 1 Known IR Scene

Figure 2 IR Scene with Different TOT

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Figure 3 IR Scene With Different Weather Conditions

3.2 Expert Aided Planner

The expert aided planner combines past experience with non-integrated engineering or decision tools. System performance charts, engineering look-up tables, and stand-alone software tools may be used to assist the planner in determining what features to include in the reference template. The planner may be able to account for various times year, times of day, material properties, and weather conditions to arrive at an accurate thermal prediction of the scene of interest. However, the process is extremely time consuming, and the reference template is again very specialized for the conditions that are considered. Since the real time conditions will probably not be identical to the ones that were assumed for the reference template, the planner does not have a great deal of confidence in reference template correlation performance. For example, if the planner expects clear weather and a scene like Figure 1, then last minute weather changes or last minute time on target changes will require a detailed analysis to determine whether or not the reference template concept will be valid for the new conditions. Because of the time consuming process of predicting the thermal properties of a scene and developing a reference template that will be valid for the specific set of conditions, last minute reference template updates are nearly impossible, and any deviations in planned weather conditions, scene conditions, or time on target could result in a scrubbed mission.

Like the Expert Manual Planner method, this method has low development costs. However, the recurring costs are high due to the costs associated with the lengthy reference template generation times, extensive intelligence data required, training of personnel and the large number of reference templates that must be generated to provide complete weather coverage for a target.

3.3 Expert System

Automated decision aides are embedded in the software of the expert system to incorporate a body of expert knowledge. Planning is still primarily a manual task, but the planner utilizes an automated expert system to provide advice and recommendations. Since the expert system guides the planner through most of the decisions, the planner does not need a great deal of expertise, and the amount of time required to generate a reference template is greatly reduced. The expert system may force the planner to take into account important considerations that could otherwise be overlooked. The expert system can help to eliminate human errors (both of omission and commission). However, the expert system is limited by the knowledge of the expert that designed the system.

Detailed intelligence data is required for scene generation, and photo interpretation is required for identification of material types. Thermal predictions are made for a very specific set of weather and environmental conditions, making the reference template specialized. Thus, changes in these conditions increase the uncertainty associated with reference template acquisition.

The development cost of an Expert System is high. Much effort must be expended in establishing a Knowledge Base for the system. The Knowledge Base must encompass all possible operations in the planning process, be able to assess the operations for correctness, and recommend or correct the faulty operations. While the method does not require expert users, extensive intelligence is still required. While the reference template generation time is improved over that of the Expert Manual and Expert Aided methods, large numbers of reference templates are still required to provide all coverage capability and there is still no level of confidence for the reference template's correlation performance provided.

3.4 Discrete Model System

The discrete model system employs mathematical simulation models representing the performance of the hardware, software, and phenomenology in all phases of reference

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template generation. Reference template generation is based on simulation results. Reference template acquisition can be simulated against synthetic imagery using the ATR algorithms. The reference template can be revised as necessary until performance is acceptable. If the weather and intelligence parameters that are assumed for the simulation are accurate, the probability of acquisition is very high. If conditions change, or if new information is provided, the reference template will have to be simulated against the new imagery to verify proper acquisition. If performance is not adequate at this point, the reference template will need to be revised and simulated again. Therefore, last minute changes in conditions could result in poor reference template performance or a scrubbed mission.

The discrete model system has a development cost less that the Expert System, but more than that of the Expert Manual or Expert Aided systems. The method still requires some training of the users and still results in large number of reference templates to provide all coverage. The main advantage of this method is that it provides a prediction of the performance of the reference template

3.5 Random Model System

The reference template for the random model system is an automatic pseudo-random selection of a large number of features extracted via filtering and thresholding of all scene features of the intelligence image. There is little development cost for the system, nearly no training is required for the planner, and no special intelligence products are needed. Reference template generation time is less than 15 minutes, allowing for near real time planning. The main drawback to this system, is that it does not take into account the IR phenomenology of the scene. The edges selected for the reference template, although evident in the intelligence photograph, may not be apparent in the real time IR image. Therefore, the probability of acquisition is unknown. For example, the roofs in Figure 3 are similar in temperature to the surrounding ground. If some of the far roof edges are selected at random, the reference template may not be correctly placed in the image upon execution of the ATR. Additionally, the profile is limited by the camera angles of the photograph

that was used. Major changes in profile may cause obscurration of selected edges. Finally, the randomly selected edges may or may not result in a unique combination, increasing the uncertainty in reference template performance to an even greater extent.

The Random Model system has low development costs and the recurring costs are low due to no training of personnel and low reference template generation times. However, the confidence associated with those reference templates is extremely low. The conditions under which the reference templates will be used are not considered at all in their development and mission success is highly questionable.

4. Automated Reference Template Generation

The Northrop Grumman Automated Reference Template Generation process automates many of the manual steps of the Discrete Model System. In addition, the process includes Performance Prediction thereby providing the user with an estimate of the correlation success of the reference template. Furthermore, the performance prediction is exercised over a wide range of external conditions (weather, time-on-target, etc.) thus giving the user an estimate of the mission's success not only for the nominal conditions, but the for variations in those conditions that might be encountered.

Northrop Grumman has acquired a database of over 800 missions of IR imagery. The process described below is currently being validated using this imagery.

The process involves three steps:

- Target Model Import/Construction

- Definition Of Parameters

- Automated Reference Template Generation And Performance Prediction

4.1 Target Model Import/Construction

A model of the target area is needed for predictions of the target area in the sensor waveband. These predictions, or synthetic images, are used for both the generation of reference templates and for the validation of those reference templates. The target model can be imported from existing databases and/or can be constructed. The construction of the target model requires minimal data: a digitized

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visual image of the target area and three control points, i.e. points identified in the image with known geo-location. This information exists today in intelligence databases. The user adds objects to the model using ordinary constructs (e.g. box, wedge) via point and click operations over the image. The geo-locations of the new objects are automatically calculated.

Relevant information required for the prediction of the sensed target area in the sensor waveband is then added. For the case of an IIR sensor, material types are selected from a hierarchical database; exact material types are not required. The material types and corresponding properties resident in an embedded database support a validated open-loop prediction of the IR response based on validated thermal and specular models. Such an open-loop prediction can be executed "on-the-fly" to support short mission planning timelines

whereas externally provided IR data typically requires time-consuming tasking orders and substantial post-processing prior to availability.

4.2 Definition Of Parameters

Mission parameters are defined by the user in order to support the automated reference template generation process. These parameters are shown in Table 2. The source of these parameters is dependent on the time frame of mission being planned. In the case of near-real time planning where time-on-target (date and time), weather, and heading are known, the parameters are typically defined explicitly by the user. For long range planning, these parameters can be defined as ranges. Weather can always be obtained from an external database if the user does not have weather information. Heading and time-of-day can be optimized at the user's request.

Table 2 Mission Parameters

Parameter	Source
Date	User
Time on Target	User
Heading	User
Temperature	Database or User
Humidity	Database or User
Cloud Type	Database or User
% Cloud Cover	Database or User
Wind Speed	Database or User
Visibility	Database or User
Barometric Pressure	Database or User
Intelligence Data Errors	Database
Sensor Errors	Database
Vehicle Errors	Database

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4.3 Reference Template Generation And Performance Prediction

The target model and mission parameters are used to automatically define a reference and to validate the correlation performance of the reference template.

A reference template is generated by selecting one or more key sets of features in the target scene. By executing an open-loop IR prediction of the target scene over a wide range of conditions and uncertainties, a ranked set of scene features which are most reliable in all conditions considered (mission profile, season, time, weather, et cetera) is determined. If needed to provide all coverage, multiple sets of features can be selected.

The reference template is executed against a series of synthetic IR images constructed from a statistical draw of variable likelihood's using a high-fidelity simulation of the ATR algorithms. Cumulative results are determined over a large range of conditions and uncertainties. Sensor system performance results are expressed as probability of target acquisition (P_{ACQ}). This process is illustrated in Figure 4. Specifics of the process vary for near-real time and long-range planning.

For long-range planning, all parameters are varied. A minimum number of feature sets are selected to provide complete all year, all weather, all heading, all times-of-day coverage, when feasible. Times and heading combinations

where there is no adequate contrast to build a successful reference template are identified. This process is illustrated in Figure 5.

For near-real time planning, the range of conditions and parameters are not as wide as they are in long-range planning. The time-of-year (and corresponding weather) is known while the time-of-day and heading can be constrained or optimized. Synthetic imagery is generated then for only those conditions and a single feature set is selected. P_{ACQ} is provided for the reference template as a function of time in order to provide the user with all times that the reference template can be used.

5. Summary

Five existing methods of reference template generation were compared to the Northrop Grumman Automatic Reference Template Generation approach. An assessment of these approaches is provided in Table 3. Existing methodologies do not provide robust reference templates with adequate levels of confidence. Northrop Grumman's Automated Reference Template Generation approach provides a discrete probability of sensor performance, reduces target planner training requirements, and increases target planning throughput by eliminating the construction of poor performing target reference data sets. Although developed for IIR sensors, the concept and process described is applicable to other advanced sensor systems.
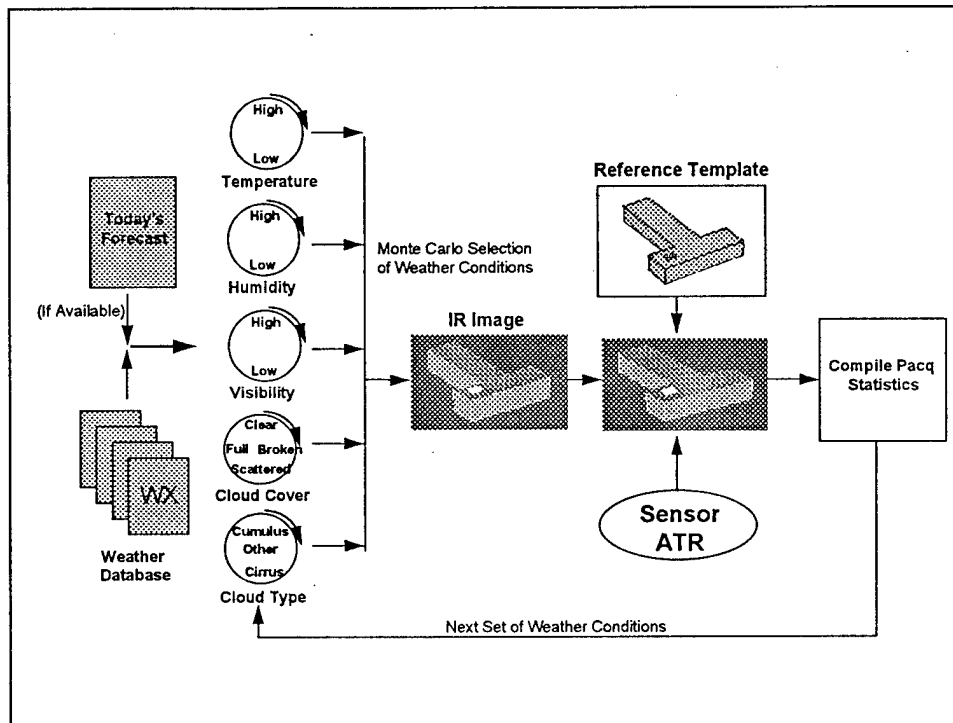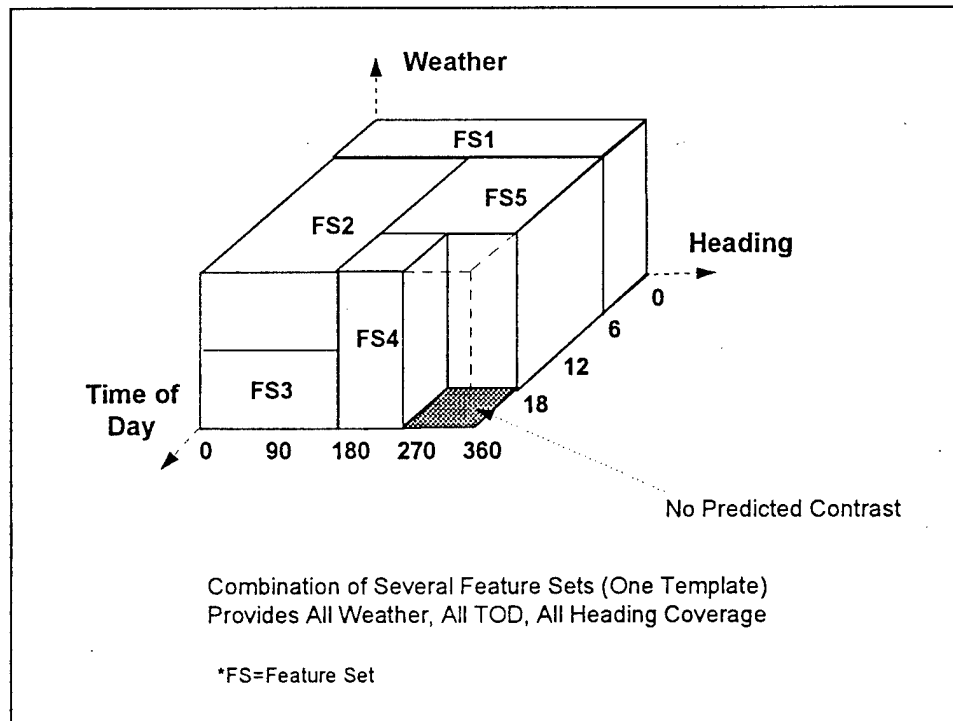
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Figure 4 Statistical Validation of P_ACQ

Figure 5 All Coverage Capability

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Table 3 System Evaluation

System\Criteria	Development Cost	Required Personnel Skills	Intelligence Required	Ref. Template Generation Time	Robustness	Confidence of Ref. Template
Expert Manual Planner	Low	Expertise in IR, ATR, and targeting	New product consisting of complex analysis, photo-interpretation and graphics	Very long (up to 4 hrs) Manual data preparation time-consuming	Unknown. Dependent upon expertise of planner	Low. Can be higher for simple, known scenarios
Expert Aided Planner	Low	Expertise in IR, ATR, and targeting	New product consisting of complex analysis, photo-interpretation and graphics	Very long (up to 8 hrs) Manual data preparation time-consuming + running off-line analysis	Unknown. Dependent upon expertise of planner and the exact conditions for which it was planned	Low. Can be higher for exact scenarios analyzed
Expert System	High	Training Required. High level of expertise not required.	New product consisting of complex analysis, photo-interpretation and graphics	Medium (2 hrs) Expert software improves timeline. Requires less manual preparation time	Unknown. Dependent upon expertise of planner and the exact conditions for which it was planned	Low. Can be higher for exact scenarios analyzed
Discrete Model System	Medium	Training Required. High level of expertise not required.	Existing intelligence products	Medium Low (1 hr)	Limited by the conditions for which it was planned	Variable (Low to High) High for exact scenarios analyzed, lower for others
Random Model System	Low	Nearly none	Existing intelligence products	Very low (< 15 min)	Very Low. Does not address the "phenomenology" at all.	Unknown
Northrop Grumman Automated Reference Template Generation	Medium	Nearly none	Existing intelligence products	Low (<30 min)	Very high. Monte Carlo simulation verifies performance for multiple scenarios	Very high

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Note: Earlier the title was: Target Planning and Performance Prediction for Advanced Technology Sensors

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Larry,

Enclosed is an updated copy of our paper presented at the AIAA Missile Sciences Conference. Please note that the title of the paper changed from Target Planning and Performance Prediction for Advanced Technology Sensors to Reference Template Generation for Automatic Target Recognition (ATR) Systems.

Sincerely,

Beth Adler
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